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COMMENTARY AND DISCUSSION ARTICLE

Scientometric sorting by importance for literatures on life cycle assessments and some related methodological discussions

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Abstract
Purpose This paper aims to sort the literatures on life cycle assessments (LCA) by their respective importance through citation and co-citation analysis and to further discuss the strengths and weaknesses of these kinds of scientometric methods in the case of LCA research.
Methods CiteSpace II was used to generate document co-citation networks based on 3,824 articles retrieved from the ISI *Web of Science* database on this topic.
Results Table 1 provides the top 50 highest cited documents in the LCA field. Here, we use two indicators, i.e., citation frequency in citation analysis and betweenness centrality metric in co-citation analysis, to measure the importance of these LCA literatures.
Conclusions Citation and co-citation analysis are useful for environmental scientists and engineers to get a better understanding of the inner structure of LCA research. However, like all other research methods, this kind of analysis has some limitations. On the one hand, Scientometric studies and related software are very dependent on ISI *Web of Science* database, but considering the ISI *Web of Science* only began to track the LCA field fairly recently, the Scopus database would probably give a fuller picture. On the other hand, since the essence of scientometrics analysis is outsiders commenting insiders, so with only citation and co-citation analysis, to our understanding of the past, present, and future of LCA field, is insufficient.

Keywords Betweenness centrality metric · Citation frequency · CiteSpace II · Document co-citation analysis · Life cycle assessments · Scientometric method

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1 Introduction

Scientometric studies investigate the structure of scientific research mainly based upon citation and co-citation analysis. Newton (1965) said, "If I have seen farther, it is by standing on the shoulders of giants". The achievements of modern scientists are also owing to the fact that they can continue to work on the basis of their predecessors and peers. As an essential part of research papers, particularly in the sciences, is the list of references pointing to prior publications. A reference is the acknowledgment that one document gives to another; and a citation is the acknowledgment that one document receives from another (Narin 1976). In general, a citation implies a relationship between a part or the whole of the cited document and a part or the whole of the citing document (Malin 1968). Citation analysis is that area of bibliometrics which deals with the study of these relationships (Smith 1981).

As one of the most important and lately developed method in citation analysis, co-citation analysis enables us to identify the groups of scientists and their publications from which conclusions can be drawn about the inner structure of research disciplines, schools, or paradigms (Small 1980). There are many co-citation networks, one of which generated in this study is document co-citation networks. Document co-citation analysis measures the number of documents that have cited a given pair of documents (Small 1973). It assumes that authors whose works are related are repeatedly cited together, and they tend to group together when analyzed, while other authors are rarely or never cited together. Co-citation analysis changes over time as the co-citation frequencies of particular works change with new developments in the focus of research efforts in a field. For example, if papers A and B are both cited by paper C, they may be said to be related to one another, even though neither directly cites the other. If papers A and B are both cited by many other papers, they have a stronger

relationship. The more papers they are cited by, the stronger their relationship is. Overall, co-citation analysis is better than mere citation analysis or just looking at the statistics for documents or authors from the Institute for Scientific Information (ISI) *Web of Science* database, although the latter also has its unique value. Because the co-citation analysis explores the relationships not only between citing and cited but also among citation networks, so it is a more in-depth approach and now has become the dominant method for the empirical study of the scientific structures and communications. Moreover, unlike traditional research output evaluation methods such as impact factors, co-citation analysis is performed at the article level, rather than the journal level. This clear advantage of co-citation analysis allows us to evaluate scientific research performance at an interdisciplinary level, since with journal-level classification, each scientific journal is classified into a major field, despite the fact that journals are progressively covering a wider array of disciplines and topics that are not properly reflected in their field categorization.

Certainly, both the methods of citation and co-citation analysis are not perfect and can be misused, so here some critical words are given upon this method. On the one hand, some deficiencies of co-citation inherited from, and so has the same problem with the citation analysis. For example, the complexity of motivation may cause many citations irregularities such as “citing without using” or “using without citing”. As to the citations motivation, Garfield (1965) believed that there are 15 kinds of them including “Paying homage to pioneers,” “Giving credit for related work (homage to peers),” and so on. Brooks’ analysis (1986) of the clustering of the citer motives showed three groupings: the first including persuasiveness, positive credit, currency, and social consensus; the second is negative credit; and the third including reader alert and operational information. Other issues of both the citation and co-citation analysis include that open access or earlier published literatures, under the same conditions, tend to get more citations.

On the other hand, there are still some problem only occurring in co-citation analysis, and the most controversial among them is how to measure the similarity. Small used Salton cosine (Small and Sweeney 1984; Small 1993) or Jaccard coefficient (Small 1973) to measure the similarity between literatures, while White and Griffith (1981) mainly used Pearson correlation coefficient to calculate the similarity between authors. In 2003, Ahgren et al. (2003) pointed out that Pearson correlation coefficient does not meet the two necessary conditions for the similarity measures and suggested methods of cosine and chi-squared distance used here; while in 2006, Leydesdorff (Leydesdorf and Vaughan 2006) proposed a view that both the Pearson correlation coefficient and cosine measure are not suitable for symmetric matrices, but fit for non-symmetric matrices. Although the discussion has been intense, academia now is still no consensus on the similarity measure method in co-citation analysis.

It must be pointed out that citation and co-citation analysis, on the whole, are excellent quantitative research methods, in nearly 60 years of development history, their effectiveness and efficiency have been proved in many scientometric researches, and the defects of citation and co-citation analysis, compared to their advantages, is apparently minor. And this paper aims to sort the literatures on life cycle assessments (LCA) by their respective importance through citation and co-citation analysis with further discussing the strengths and weaknesses of these kinds of scientometric methods and what environmental scientists and engineers, especially LCA practitioners and researchers, can and cannot know from these analyses.

2 Data and means

The data used in this article come from the *Web of Science* database which is published by the ISI in the USA. The data retrieval strategy in the present paper is the following:

Topics = (life cycle assessments)
Refined by: Document Type=(ARTICLE)
Timespan=All Years
Databases=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, and CPCI-SSH.
Lemmatization = On

The full bibliographic records including authors, titles, abstracts, and reference lists for 3,248 articles were retrieved and downloaded in January 25, 2012. CiteSpace II was used to generate co-citation networks. CiteSpace is developed by Chaomi Chen from Drexel University (http://cluster.cis.drexel.edu/~cchen/citespace/).

3 Findings

Table 1 lists the top 50 highly cited documents in the LCA field using document co-citation network analysis. Different from the majority of studies conducted with CiteSpace, in the present research, CiteSpace is not treated primarily as a “knowledge domain visualization” tool that paints a picture of how science grows and evolves over time (Chen 2004). We treat CiteSpace simply as a calculation tool and try to establish a comprehensive and multidimensional index system using several already-established and validity-verified indicators in CiteSpace to assess the academic level of specific scientific publications of various research topics including the Wenchuan earthquake (Qian 2012), bioenergy (Qian 2013a),

Table 1 The top 50 highly cited documents in the life cycle assessments field

Frequency	Centrality	Title	Author	Source/Press	Year
229[a]	0	*Environmental management—LCA—general principles and practices*	International Organization for Standardization	ISO 14040	2006
211	0.07	*Environmental management—LCA—general principles and practices*	International Organization for Standardization	ISO 14040	1997
178[a]	0	*Environmental management—LCA—requirements and guidelines*	International Organization for Standardization	ISO I4044	2006
167	0.03	The Second Dutch LCA-Guide, published as book	Klöpffer	*International Journal of Life Cycle Assessment*	2002
149[a]	0.01	*The Eco-indicator 99: a damage oriented method for life-cycle impact assessment*	Goedkoop et al.	Pré Consultants	2000
136[a]	0.08[a]	*Guidelines for life-cycle assessment: a "Code of practice"*	Consoli et al.	Society for Environmental Toxicology and Chemistry	1993
132	0.14	*Environmental life cycle assessment of products: guide*	Heijungs et al.	Centre of Environmental Science	1992
122	0.04	*Environmental management—LCA—goal and scope definition and inventory analysis*	International Organization for Standardization	ISO 14041	1998
92	0.02	*Life cycle assessment—an operational guide to the ISO standards*	Guinée et al.	Kluwer Academic	2002
92	0.02	*Environmental management—LCA—Life cycle impact assessment*	International Organization for Standardization	ISO 14042	2000
86	0.01	IMPACT 2002+: a new life cycle impact assessment methodology	Jolliet et al.	*International Journal of Life Cycle Assessment*	2003
85	0.02	*Environmental assessment of products: volume 1: methodology, tools and case studies in product development*	Wenzel et al.	Chapman & Hall	1997
68	0	Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change	Searchinger et al.	*Science*	2008
67	0	Life cycle assessment part 1: framework, goal and scope definition, inventory analysis, and applications	Rebitzer et al.	*Environment International*	2004
66	0.01	System boundary selection for life cycle inventories using hybrid approaches	Suh et al.	*Environmental Science & Technology*	2004
66	0	The tool for the reduction and assessment of chemical and other environmental impacts (TRACI)	Bare et al.	*Journal of Industrial Ecology*	2003
63	0	System boundaries and input data in consequential life cycle inventory analysis	Ekvall et al.	*International Journal of Life Cycle Assessment*	2004
62	0	*Environmental assessment of products, volume 2: scientific background*	Hauschild et al.	Chapman & Hall	1998
57	0	Ethanol can contribute to energy and environmental goals	Farrell et al.	*Science*	2006
56	0.02	Priority assessment of toxic substances in life cycle assessment. Part I: calculation of toxicity potentials for 181 substances with the nested multi-media fate, exposure and effects model USES–LCA	Huijbregts et al.	*Chemosphere*	2000
56	0	Land clearing and the biofuel carbon debt	Fargione et al.	*Science*	2008
55	0.02	Life cycle assessment Part 2: current impact assessment practice	Pennington et al.	*Environment International*	2004
55	0.02	Life cycle assessment and its application to process selection, design and optimisation	Azapagic	*Chemical Engineering Journal*	1999
53	0	*Environmental management—life cycle assessment—life cycle interpretation*	International Organization for Standardization	ISO 14043	2000
51	0.01	Methodological aspects of life cycle assessment of integrated solid waste management systems	Finnveden	*Resources, Conservation and Recycling*	1999
50	0	*Perspectives in life cycle impact assessment: a structured approach to combine models of the technosphere, ecosphere and valuesphere*	Hofstetter	Kluwer Academic	1998

Table 1 (continued)

Frequency	Centrality	Title	Author	Source/Press	Year
48	0	Life cycle assessment of milk production—a comparison of conventional and organic farming	Cederberg	*Journal of Cleaner Production*	2000
46	0.02	Allocation in ISO 14041—a critical review	Ekvall et al.	*Journal of Cleaner Production*	2001
46	0.02	Best available practice regarding impact categories and category indicators in life cycle impact assessment	Udo de Haes et al.	*International Journal of Life Cycle Assessment*	1999
45	0	*The hitch hiker's guide to LCA*	Baumann et al.	Studentlitteratur	2004
45	0	Life cycle assessment of various cropping systems utilized for producing biofuels: bioethanol and biodiesel	Kim et al.	*Biomass and Bioenergy*	2005
45	0	USEtox—the UNEP-SETAC toxicity model: recommended characterization factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment	Rosenbaum et al.	*International Journal of Life Cycle Assessment*	2008
44	0	The application of life cycle assessment to process optimisation	Azapagic et al.	*Computers & Chemical Engineering*	1999
41	0	Life cycle assessment of energy from solid waste—part 1: general methodology and results	Finnveden et al.	*Journal of Cleaner Production*	2005
40	0	Recent developments in life cycle assessment	Finnveden et al.	*Journal of Environmental Management*	2009
39	0	*Exergy analysis of thermal, chemical, and metallurgical processes*	Szargut et al.	Hemisphere Publishing Corporation	1988
39	0	Comparison of three different LCIA methods: EDIP97, CML2001 and Eco-indicator 99	Dreyer et al.	*International Journal of Life Cycle Assessment*	2003
38	0	*Environmental life cycle assessment of goods and services: a n input-output approach*	Hendrickson	Resources for the Future	2006
37	0	Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment	Haas et al.	*Agriculture, Ecosystems & Environment*	2001
35	0.01	Life-cycle impact assessment: striving towards best practice	Udo de Haes et al.	SETAC Foundation for Environmental Education	2002
35	0	Avoiding co-product allocation in life-cycle assessment	Weidema	*Journal of Industrial Ecology*	2000
34	0	*Environmental life-cycle assessment*	Curran	McGraw Hill	1996
32	0	*Integrated solid waste management: a lifecycle inventory*	White	Springer	1995
31	0	Changes in atmospheric constituents and in radiative forcing	Forster et al.	*Climate change*	2007
31	0	Life cycle assessment of conventional and organic milk production in the Netherlands	Thomassen et al.	*Agricultural systems*	2009
31	0	*A conceptual framework for life-cycle impact assessment*	Fava	Society of Environmental Toxicology and Chemistry and SETAC Foundation for Environmental Education	1993
30	0	*Industrial ecology*	Graedel et al.	Prentice Hall	1995
30	0	Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels	Hill et al.	*Proceedings of the National Academy of Sciences*	2006
30	0	Data quality management for life cycle inventories—an example of using data quality indicators	Weidema et al.	*Journal of Cleaner Production*	1996
30	0	*The analytic hierarchy process: planning, priority setting, resources allocation*	Saaty	McGraw Hill	1980

[a] This value is recalculated and revised by artificial

psycho-oncology (Qian 2013b) as well as LCA, which are evaluated by using this method.

Here, we use two indicators for measuring the importance of these LCA research studies. One is the citation frequency, the use of this indicator constituted the basis of citation analysis; if an academic literature cited very few, its scientometric significance or value seems lower, so only the top 50 high cited and used documents are selected for further analysis in this paper. And the other is Freeman's betweenness centrality metric (Freeman 1979) as an indicator of co-citation analysis, which was used by Leydesdorff (2007) in scientometric research. Betweenness centrality is a measure of a node's centrality in a network. It is equal to the number of shortest paths from all vertices to all others that pass through that node. Betweenness centrality is a more useful measure (than just connectivity) of both the load and importance of a node. In the perspective of scientometrics, literatures with higher value in betweenness centrality usually play a very important role in the process of transferring information.

4 Discussion

Citation and co-citation analysis, like any other quantitative analysis, depends on the correctness and accuracy of data and algorithm included, and this kind of correctness and accuracy are always relative. So in order to make the evaluation more scientific, objective, and fair, we should, firstly, note whether our sampling bias; secondly, keep open attitude to other algorithms; thirdly, integrate qualitative and quantitative analyses. Below are further discussions from two aspects contacting the theme of this article, i.e., sorting the literatures on LCA by their respective importance through citation and co-citation analysis with further inquiring into what environmental scientists and engineers can and cannot know from these analyses.

On the one hand, different lists of names tell us different things about the research community. Since there are some bibliometric analysis methods other than co-citation analysis and not always through CiteSpace, such as an alternative method proposed by Cobo et al. (2011), and the Essential Science Indicators produced by the Thomson Reuters group, also describes the most influential documents and emerging research fronts, is another. But the design of these methods is not flexible enough compared to the use of CiteSpace II, so related software and algorithm, without prejudice to their validity, should be simplified and made compatible as much as possible.

Maybe as the characteristics of environmental engineering, we can see in Table 1, the nine of ten "top citations," or the vast majority documents with highest value in centrality, are actually "grey" literature (standards, reports, etc. but not journal articles), and these kinds of documents often cannot be retrieved directly from the ISI *Web of Science*. Similarly, we can see from the list of authors in the table of analysis results that actors other than academic researchers, such as the Society of Environmental Toxicology and Chemistry (SETAC) people, the United Nations Environment Program (UNEP) people, journals staffs and editors, consultants, and government commissioners and officials make up a significant part of the LCA "eco-system." Considering that the ISI *Web of Science* only began to track the LCA field fairly recently (Baumann 2002a, b), the Scopus would probably give a fuller picture, or better still, Google Scholar. Until now, many scientometric software applications, such as CiteSpace, cannot be used to analyze the Scopus database. Here, related scientometric software that is not only user-friendly but also compatible with more types of databases or algorithms should be devised so that environmental science researchers can easily use it for analysis in their fields of study, such as LCA.

On the other hand, citation and co-citation analysis are useful for environmental scientists and engineers, particularly newcomers to this field, to get a better understanding of the inner structure of LCA research and to learn what the most important documents in this area are; however, these analyses on LCA research also need to position themselves. Although no direct evidence is given in this paper to justify the methodological choices, many co-citation analyses of other disciplines using CiteSpace II, such as the classic study by Chaomei Chen (2006), can indirectly prove the effectiveness of this approach. Of course, like all other research methods, citation and co-citation analysis also has some limitations, at least in the case of LCA research. In the view of the author, these quantitative and computational analyses should be transcended in some ways so as to help newcomers to the LCA community better.

Since the essence of the scientometrics analysis is outsiders commenting insiders, so in the end of this paper, I must say that with only scientometric and bibliometric analysis, our understanding of the past, present, and future of LCA is insufficient, and in some cases, it is of little help to newcomers to this field. It is suggested that not only the results of citation and co-citation analysis should be learned but also the classical works themselves listed on the results of document co-citation analysis, such as the ISO standards and the article by Klöpffer (2002), be carefully read. It is also strongly recommended that at least the series of historical papers published in the *International Journal of Life Cycle Assessment*, such as the writings of Hunt and Franklin (1996) and the latest research articles on LCA field published in social science journals, such as the article of Freidberg (2013), are to be carefully studied. This is because compared to the computational analysis, historical papers can help us better understand the foundations of LCA, and the economics and sociology papers on LCA may tell us the present situation of LCA and the direction it will take.

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